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Transparent conducting films made of different carbon nanotubes

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Carbon nanotube (CNT) films on transparent rigid substrates could be a substitute for currently available transparent electrodes of indium tin oxide (ITO) or fluorine doped tin oxide (FTO). In this communication, we present sheet resistance (R_s) and transmittance at 550 nm (T) data of CNT films prepared by spray-coating on a glass substrate. Spray-coating was carried out with dilute suspensions of the CNTs in a sodium dodecylbenzenesulfonate (SDBS) aqueous solution. Different CNT materials, including various single-walled (SW), double-walled (DW) and multi-walled (MW) CNTs were studied, and several CNT pre-treatments (air oxidation, covalent functionalization, and high speed centrifugation) and film post-treatments (water and nitric acid washing) were also tested.

All the studied SWCNTs, as well as the CVD-grown MWCNTs, demonstrated $R_s < 10^6$ Ω/sq for T ~ 80%, confirming good possibilities for the preparation of transparent electrodes. The best electro-optical properties were measured for laser-grown SWCNT films, which reached R_s ~ 900 Ω/sq and T > 70%. These values are not far from the characteristics of FTO/glass at identical measurement conditions (R_s = 109 Ω/sq and T > 76%).

In certain cases, conductivity improved after pre-treating CNTs with air-oxidation followed by HCl reflux. In fact, the R_s of arc-dischange SWCNT films with T ~ 60% decreased from $9.5 \cdot 10^5$ to $1.1 \cdot 10^4$ Ω/sq. However, R_s increased from $9.1 \cdot 10^2$ to $2.8 \cdot 10^4$ Ω/sq when laser-grown SWCNTs were pre-treated with identical processes. High speed centrifugation of the CNT dispersions caused a slight increase in R_s (usually less than one order of magnitude). Covalent functionalization of the SWCNTs led to an increase in the film R_s, the variation being dependent on the functionalization method. Functionalization of arc-discharge SWCNTs with pyrrole moieties through the diazonium salts route modified the R_s of a film with T ~ 60% from $9.5 \cdot 10^4$ to $1.7 \cdot 10^{13}$ Ω/sq. Otherwise, HiPco SWCNTs functionalization with lysine moieties through 1,3-dipolar cycloaddition only led to a variation from $3.0 \cdot 10^5$ to $3.2 \cdot 10^6$ Ω/sq at T = 72%.

Film post-treatments by water and nitric acid washing substantially decreased R_s values. For a HiPco SWCNT film with T = 72%, R_s decreased from $3.0 \cdot 10^5$ to $2.0 \cdot 10^4$ Ω/sq after water washing, and to $3.5 \cdot 10^3$ Ω/sq after nitric acid washing. For a laser-grown SWCNT film with T = 67%, R_s decreased from $2.2 \cdot 10^3$ to $7.2 \cdot 10^2$ Ω/sq after nitric acid washing.

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